NBS TECHNICAL NOTE

466

Matching Fingerprints by Computer

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in three broad program areas and provides central national services in a fourth. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, and the Center for Radiation Research.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement, coordinates that system with the measurement systems of other nations, and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Standard Reference Data and a group of divisions organized by the following areas of science and engineering:

Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic Physics—Cryogenics[2]—Radio Physics[2]—Radio Engineering[2]—Astrophysics[2]—Time and Frequency.[2]

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to methods, standards of measurement, and data needed by industry, commerce, educational institutions, and government. The Institute also provides advisory and research services to other government agencies. The Institute consists of an Office of Standard Reference Materials and a group of divisions organized by the following areas of materials research:

Analytical Chemistry—Polymers—Metallurgy — Inorganic Materials — Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides for the creation of appropriate opportunities for the use and application of technology within the Federal Government and within the civilian sector of American industry. The primary functions of the Institute may be broadly classified as programs relating to technological measurements and standards and techniques for the transfer of technology. The Institute consists of a Clearinghouse for Scientific and Technical Information,[3] a Center for Computer Sciences and Technology, and a group of technical divisions and offices organized by the following fields of technology:

Building Research—Electronic Instrumentation — Technical Analysis — Product Evaluation—Invention and Innovation— Weights and Measures — Engineering Standards—Vehicle Systems Research.

THE CENTER FOR RADIATION RESEARCH engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center for Radiation Research consists of the following divisions:

Reactor Radiation—Linac Radiation—Applied Radiation—Nuclear Radiation.

---

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

UNITED STATES DEPARTMENT OF COMMERCE
C. R. Smith, Secretary
NATIONAL BUREAU OF STANDARDS • A. V. Astin, Director

NBS TECHNICAL NOTE 466

ISSUED JULY 1968

Matching Fingerprints by Computer

J. H. Wegstein and J. F. Rafferty

Center for Computer Sciences and Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

and

Walter J. Pencak

Federal Bureau of Investigation
Washington, D. C. 20535

NBS Technical Notes are designed to supplement the Bureau's regular publications program. They provide a means for making available scientific data that are of transient or limited interest. Technical Notes may be listed or referred to in the open literature.

For sale by the Superintendent of Documents, Government Printing Office
Washington, D.C., 20402 - Price 20 cents

Matching Fingerprints by Computer

by J.H. Wegstein, J.F. Rafferty, and W.J. Pencak

A procedure is described for determining whether two fingerprint impressions were made by the same finger. The procedure uses the X and Y coordinates and the individual directions of the minutiae (ridge endings and bifurcations). The identity of two impressions is established by matching a constellation or group of minutiae in one impression with a corresponding constellation in the other impression in terms of the relative distances and relative angles of the minutiae.

Key words: Computerized-fingerprint-identification, fingerprints, pattern-recognition.

1. Introduction

Several approaches have been made to automatic fingerprint identification including holographic techniques.[1,2] The techniques that use details of a fingerprint such as cores, deltas, ridge counts, ridge endings, and ridge bifurcations tend to be specialized according to the method by which the information is taken from the fingerprint. Thiebault[3] has described a technique using the directions of minutiae (ridge endings and bifurcations) where the data are obtained by a special camera that photographs the finger. Where a human operator identifies the core and delta as a reference axis, a matching technique has been developed that utilizes only the positions of minutiae.[4] The technique described in this paper is intended primarily for use with an automatic reader that reads minutiae directly from a fingerprint card without identifying cores and deltas.

This paper describes a procedure for matching fingerprint impressions by computer using only two types of minutiae: ridge endings and bifurcations. While it is anticipated that minutiae data may soon be read automatically by machine, the work reported in this paper utilizes data read manually. Each fingerprint impression used is photographed and enlarged by a factor of 10. The minutiae on each of these enlargements are then marked with a pencil on a piece of transparent plastic laid over the enlargement.

Since a ridge ending in one print may appear as a bifurcation in another print from the same finger, no distinction is made between ridge endings and bifurcations in recording data. For each of these minutiae, both a location and direction are defined as shown in Figure 1. If the areas marked B are considered as ridges, then point P is the location of a ridge ending and the line GP defines the direction of this minutia. If the areas marked A are considered as ridges, then point P is the location of a bifurcation, and the line GP defines the direction associated with this minutia. Minutiae for two fingerprint impressions identified as IIP2 and IIP4 are shown in Figures 2 and 3.

The transparency is next taped to a drawing board so that all minutiae markings fall in the first quadrant of an X-Y coordinate system. The X axis is set parallel to the horizontal lines on the standard fingerprint card from which the print was photographed. The X and Y coordinates of each minutia, as shown in Figure 1, are then read in millimeters and recorded. The angle θ which the minutia direction makes with the X axis is recorded in degrees. The value of θ may range from 0 to 360 degrees. Each minutia is also given an identification number P. A table of data is thus prepared consisting of four columns of numbers P, X, Y, and θ for each fingerprint impression to be studied.

2. The Technique for Matching Fingerprints

This matching procedure is based on matching a constellation or group of minutiae formed about a particular minutia called the nucleus from one impression with a corresponding constellation from another impression. Figure 4 shows such a constellation using a minutia labeled a as a nucleus. Although a particular constellation flexes and stretches, it retains a certain pattern identity in impressions taken from the same finger over a period of years.[5] Matching just one constellation from one impression with a corresponding constellation from another impression appears to be sufficient for concluding that both impressions were made by the same finger.

Both relative distances and relative angles are used to match a constellation in one fingerprint impression with a similar constellation from another impression. The computer works with two minutiae at a time, such as a and b in Figure 4, from each of two different sets of impression data. As shown in Figure 5, it attempts to relate the pair of minutiae a and b from Impression 1 with a pair of minutiae e and f from Impression 2. Starting with minutiae a and b, the computer computes ΔS the distance between the minutiae, $\Delta\theta_1$ the difference between the angles of these minutiae, and $\Delta\gamma_1$ the angle between the direction of minutia a and the direction of the distance vector to minutia b. Similarly, values for ΔS_2, $\Delta\theta_2$, and $\Delta\gamma_2$ are computed with respect to minutiae e and f in Impression 2. Next, the differences

$$\Delta S = \Delta S_2 - \Delta S_1$$
$$\Delta\theta = \Delta\theta_2 - \Delta\theta_1$$
$$\Delta\gamma = \Delta\gamma_2 - \Delta\gamma_1$$

are computed. If ΔS is less than KS, $\Delta\theta$ is less than $K\theta$, and $\Delta\gamma$ is less than $K\gamma$ then a score S is set equal to one and pair ab is considered matched with ef. KS, $K\theta$, and $K\gamma$ are parameters that must be adjusted for optimum performance. The computer next relates minutia a to another minutia such as c in Figure 4. If the pair ac can be matched with e and some other minutia in the second impression, the score is increased by one. This process is repeated until the score S reaches a predetermined value SM at which time Impression 1 is considered to be matched with Impression 2, and the computer prints "MAKE". If the score S fails to reach SM after S3 tries, the score S is reset to zero and the computer tries to find new pairs ab and ef that will establish a and e as nuclei for constellations that match. SM and S3 are also adjustable parameters.

3. Filing Minutia Data

Prior to attempting to match fingerprints the computer pre-processes each set of data by reading in the table of values of P, X, Y, and θ for each fingerprint impression. A typical impression will provide about 75 minutiae. For each minutia point, the computer computes an auxiliary variable φ where φ = θ if θ is less than or equal to 180° and φ = θ - 180 if θ is greater than 180°. The minutia data are next sorted so that the corresponding values of φ are in ascending order. Thus a minutia whose θ is 1° or 181° will be near the beginning of the table and a minutia with a θ value of 179° or 359° will be near the end of the table. The table of values of P, X, Y, and θ ordered according to φ is next written on magnetic tape along with an identification number (Ident) for the impression and a number (IMX) which is the total number of points taken from the impression. Minutia data for numerous fingerprint impressions have thus been stored on magnetic tape for matching studies.

4. Sequencing the Search for a Match

The complete logical details of the computer program for matching fingerprint impression data are given in the flow diagrams in the Appendix. In the following text, numbers in parentheses refer to box numbers in the flow diagrams. Text in parentheses elaborates details of the flow diagrams and can be safely ignored by the non-programmer.

The operator first identifies two impressions that are know to be in the magnetic tape file (0), for example, Ident 1 = IIP2 and Ident 2 = IIP4. IIP2 and IIP4 are two impressions from the same finger taken about three years apart and the data from these will be used here in illustrating the procedure. Their minutiae tracings are shown in Figures 2 and 3.

The computer next reads from magnetic tape a table of data for each of the two impressions (1). The values of φ as explained earlier are re-computed and entered as a fifth column in each table (2-13). Figure 6 shows the middle portion of each table. The leftmost column in each table, I, is the line number and is not part of the table itself. (For convenience in programming, the numbers in these tables are identified as elements in a three dimensional array A_{INK}. Thus $A_{44\ 3\ 2}$ is the same as the 44th value of Y in IIP4 and is equal to 202.)

The search for a match begins by finding the first minutia in IIP2 with a φ greater than or equal to 90°. This minutia, P=8, becomes the a referred to in Figure 5 and the next minutia, P=42, would become the b. Similarly, in table IIP4, minutia 40 becomes e and minutia 44 would become f. (Boxes 2-13 locate the line numbers corresponding to a and e and also determine the center of gravity of the area covered by the minutiae from each of the impressions.)

Before attempting the match illustrated in Figure 5, the computer first checks to see if minutiae a and e are pointing in approximately the same direction by computing $\Gamma\theta = \theta(a) - \theta(e)$. If $\Gamma\theta$ is less than $M\theta$, an adjustable parameter, the computer goes on to check whether minutiae a and e are in the same neighborhood in the fingerprint. This is accomplished by comparing differences in X andY with parameters KX and KY respectively (22-22.1). These measures of X and Y are referred to the center of gravity of the area covered by the minutiae of each impression to compensate for the arbitrary location of the minutiae tracings with respect to the X-Y coordinate axes.

In the illustrative data, minutiae 8 and 40 point in the same direction, but their values of X differ by an excessive amount. As referenced to the center of the pattern, the maximum difference allowed in this example is KX = 30 mm. Therefore minutia 40 is rejected (22.3) and the computer begins to step through the IIP4 data in a zig-zag pattern looking for an acceptable minutia e. (Subroutine "Zip-Zap" performs this index stepping.) The first steps of the path taken in searching for e are shown at the upper right of Figure 6. The computer will give up the search when $|\varphi(a) - \varphi(e)|$ becomes greater than $M\theta = 30°$ (40), or when the IIP4 data have been exhausted. In this example an e corresponding to minutia point 22 is found to be satisfactory. The computer therefore takes minutia 42 in IIP2 as b and begins a zig-zag search of the IIP4 data for a satisfactory f. This path is illustrated at the lower right of Figure 6.

When the possible values for f are exhausted, e is advanced another step along its zig-zag path and f begins a new zig-zag search. When the possible values for e are exhausted, b is advanced another step along its zig-zag path and both e and f are reset and restarted in their search. Similarly, when necessary, a also takes steps along a zig-zag path and each of the other points are restarted in succession.

In this example a score is achieved when a is 42 and b is 24 in IIP2 while e is 42 and f is 24 in IIP4. This changes the search pattern. a and e are now held stationary while b and f execute zig-zag search patterns (q = 2 in the flow charts). In the example, the score S quickly advances to SM = 4 and the computer prints "MAKE" followed by the table:

IIP2		IIP4	
a	b	e	f
42	24	42	24
42	41	42	41
42	22	42	22
42	79	42	79

The resulting matching constellations are shown in Figure 7.

5. Conclusion

The various parameters used in this procedure are listed below along with typical values and brief explanations of their functions.

Parameter	Function	
$K\theta=8$ $KS=6$ $K\gamma=6$	Scoring parameters.	$K\theta$ also terminates the range of f if differences between certain φ values exceed $K\theta$.
$M\theta=35$	Skips steps of e by noting if a and e are not in the same direction. Skips steps of f by noting if b and f are not in the same direction. Sets stops on range of e if φ angle between a and e exceeds $M\theta$. Sets stops on range of f if φ angle between b and f exceeds $M\theta$.	
SM=4	Score required to "MAKE".	
K1=5	Maximum number of steps a can take.	
K2=10	Maximum number of steps b can take for a given a.	
K3=15	Maximum number of steps b can take while looking for another score after score accumulation has begun and a and c are held stationary.	
KX=35	Maximum allowed difference in X values for a and e or b and f where each X is measured from the center of gravity of the rectangular area covered by minutiae.	
KY=41	Maximum allowed difference in Y values for a and e or b and f where each Y is measured from the center of gravity of the rectangular area covered by minutiae.	

Numerous computer runs must be made with fingerprint data from a given reader to determine optimum values for these parameters. Ideally, impressions from the same finger should always give a "MAKE" when compared and impressions from different fingers should always give a "NO" when compared. From experiments performed to date it appears feasible to find a set of parameters that will always give a "MAKE" when two impressions from the same finger are compared. However, these same parameters may on rare occasions also give a "MAKE" when two impressions from different fingers are compared. This flaw may be tolerated in a working system because human beings, who must always confirm identifications, can readily detect these false matches.

Computations to date indicate that this matching technique is much more reliable than a previously reported technique that emphasized compression of fingerprint data for filing.[6]

The authors are indebted to the Identification Division of the Federal Bureau of Investigation for its assistance and support in the preparation of this paper.

References

1. Yefsky, S.A., Editor, Proceedings of the First National Symposium on Law Enforcement Science and Technology, 1967, Thompson Book Company.

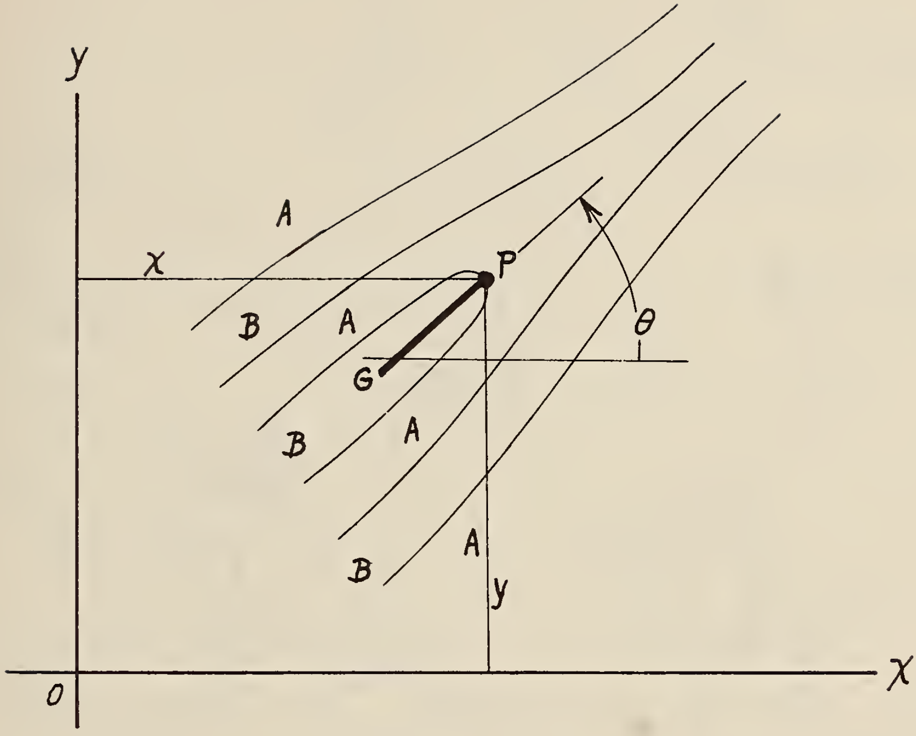
2. Trauring, M., Automatic Comparison of Finger-Ridge Patterns. Nature 197, 4871 (March 1963), 938-940.

3. Thiebault, R., "Automatic Process for the Identification of Fingerprints," Proceedings, International Symposium on Automation of Population Register Systems, Vol. 1, Jerusalem, Israel, 1967, 207-226.

4. Kingston, C.R. and Rudie, D.D., NYSIIS Fingerprint Classification Methods Study Status Report, October 1966, The New York State Identification and Intelligence System, Albany, N.Y., 1966.

5. Wegstein, J.H. and Rafferty, J.F., "Machine Oriented Fingerprint Classification System," Proceedings of the First National Symposium on Law Enforcement Science and Technology, 1967, Thompson Book Company.

6. Wegstein, J.H., A Computer Oriented Single-Fingerprint Identification System, National Bureau of Standards Technical Note 443, U.S. Government Printing Office, Washington, D.C., 1968.



Location and Direction of a Minutia

Figure I.

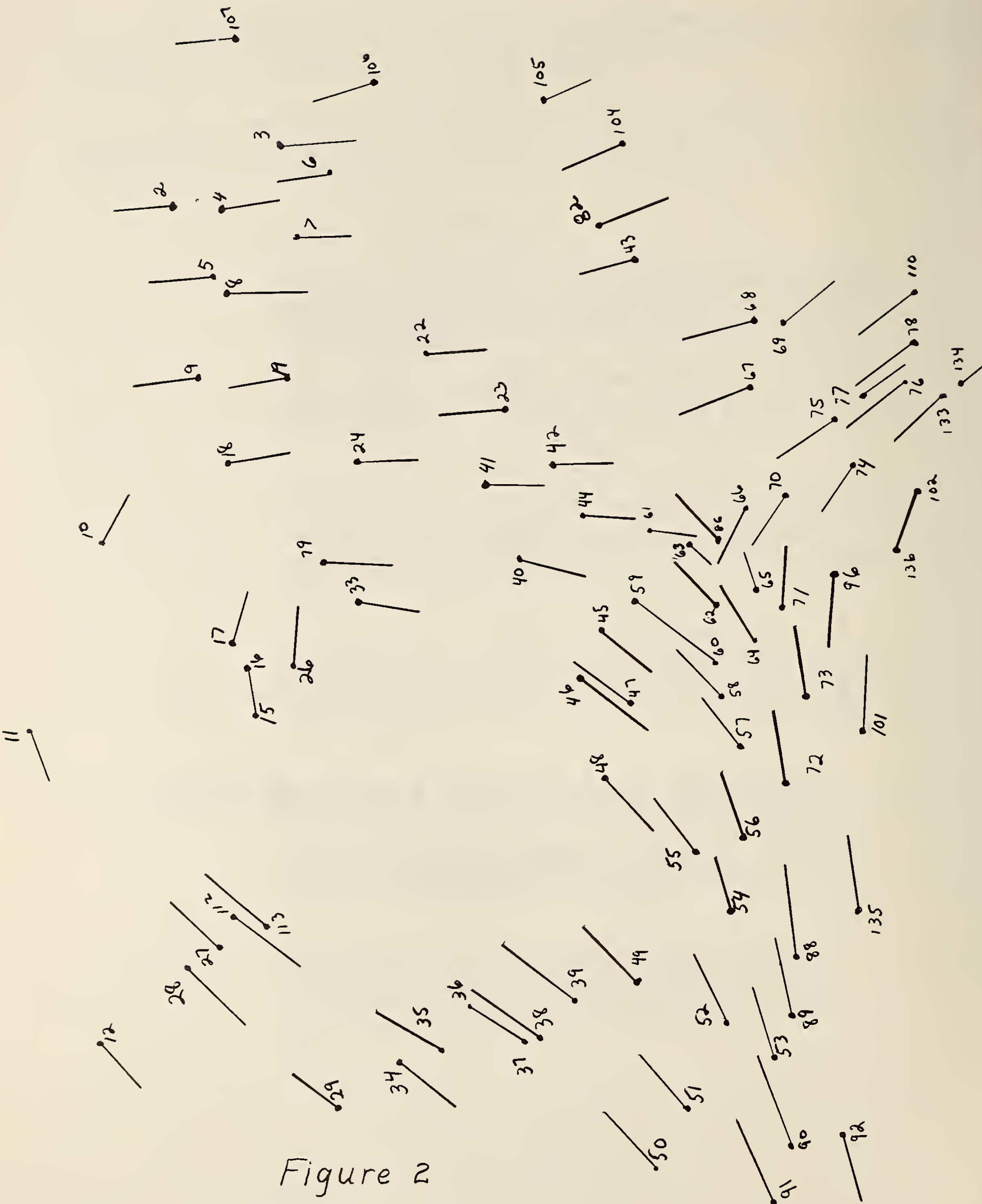
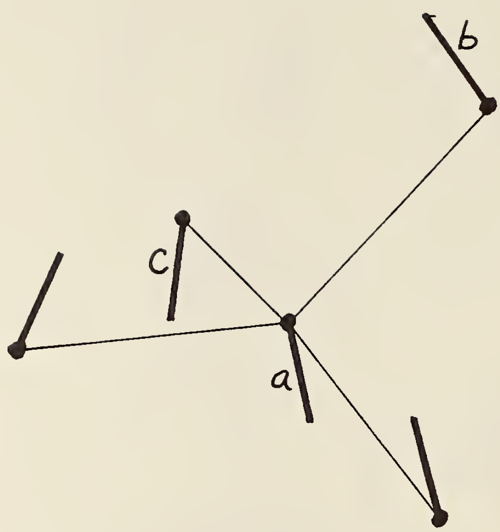


Figure 2

Impression IIP2

Figure 3
Impression IIP4



Constellation of Minutiae

Figure 4.

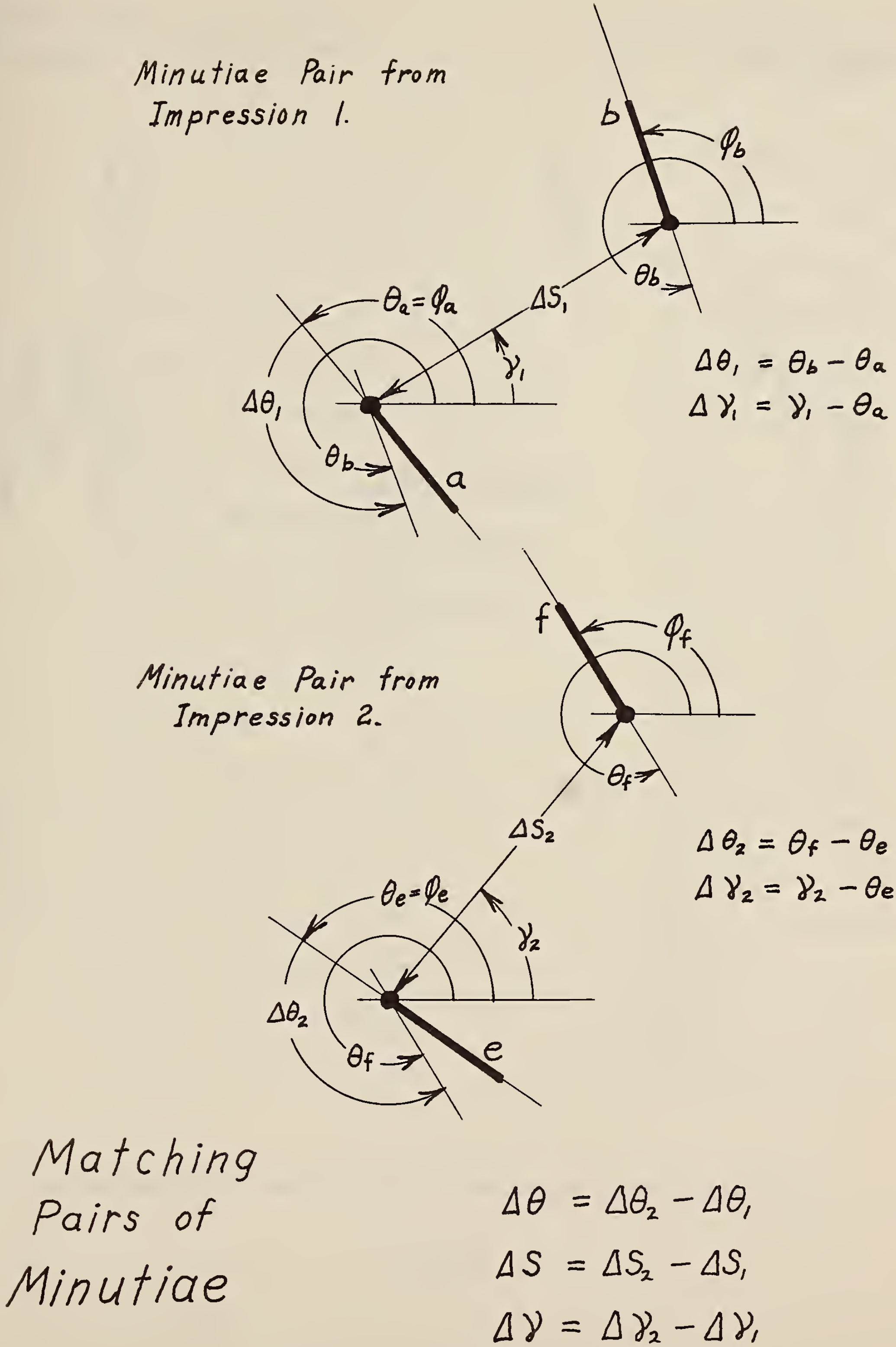

Minutiae Pair from Impression 1.
b
φb
θb
a
θa=φa
ΔS1
γ1
Δθ1
θb
Δθ1 = θb − θa
Δγ1 = γ1 − θa
Minutiae Pair from Impression 2.
f
φf
θf
ΔS2
θe=φe
γ2
Δθ2
θf
e
Δθ2 = θf − θe
Δγ2 = γ2 − θe
Matching Pairs of Minutiae
Δθ = Δθ2 − Δθ1
ΔS = ΔS2 − ΔS1
Δγ = Δγ2 − Δγ1

Figure 5.

K=1

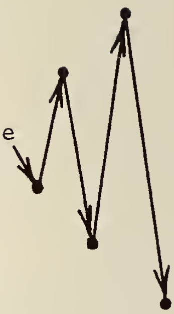
Impression IIP2
IMX = 91

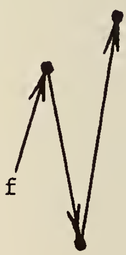
I	P	X	Y	θ	φ		
40	29	208	222	233	53		
41	47	296	157	233	53		
42	38	223	178	235	55		
43	37	222	181	236	56		
44	36	230	193	58	58		
45	35	220	199	239	59		
46	40	328	181	75	75		
47	33	318	217	81	81		
48	61	333	153	83	83		
49	44	337	168	85	85		
50	79	328	224	87	87		
51	41	344	189	89	89		
52	8	385	245	90	90	a	
53	42	348	174	91	91		b
54	7	397	229	91	91		
55	24	349	217	92	92		
56	22	372	201	93	93		
57	5	388	247	274	94		
58	107	441	242	274	94		

K=2

Impression IIP4
IMX = 74

I	P	X	Y	θ	φ		
40	31	225	229	249	69		
41	46	258	193	70	70		
42	39	195	181	254	74		
43	37	183	186	256	76		
44	36	186	202	77	77		
45	40	281	215	90	90	e	
46	44	297	204	100	100		
47	61	298	188	100	100		
48	33	258	244	110	110		
49	24	291	255	111	111		
50	138	230	122	111	111		
51	41	297	227	114	114		
52	79	264	252	114	114		
53	42	307	215	116	116		
54	22	319	254	116	116	e	
55	23	316	230	300	120		f
56	82	360	228	121	121		
57	43	353	226	303	123		
58	67	344	180	305	125		



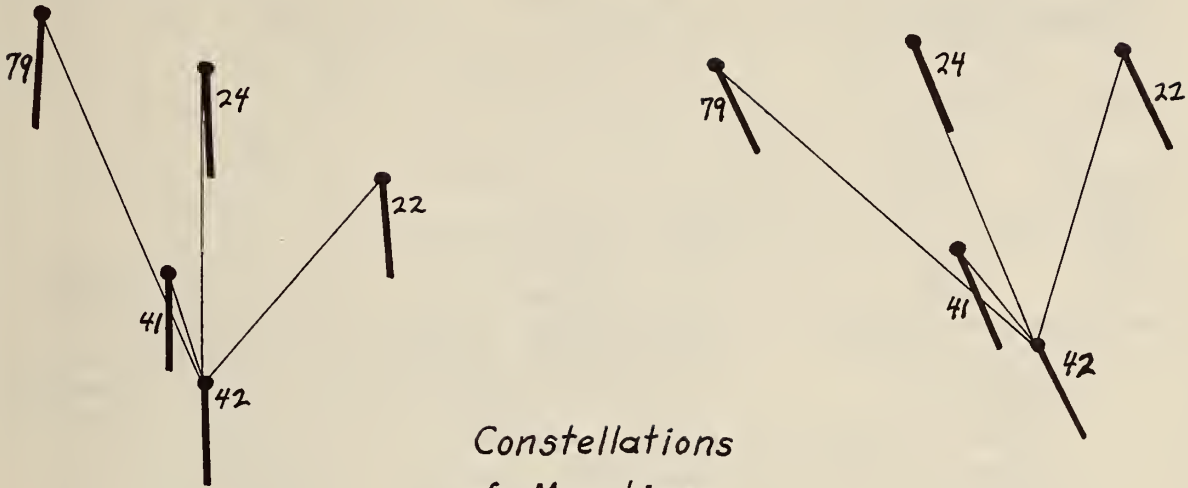


A Portion of the Minutia Data from Two Fingerprint Impressions

Figure 6.

Fingerprint Impression IIP2

Fingerprint Impression IIP4



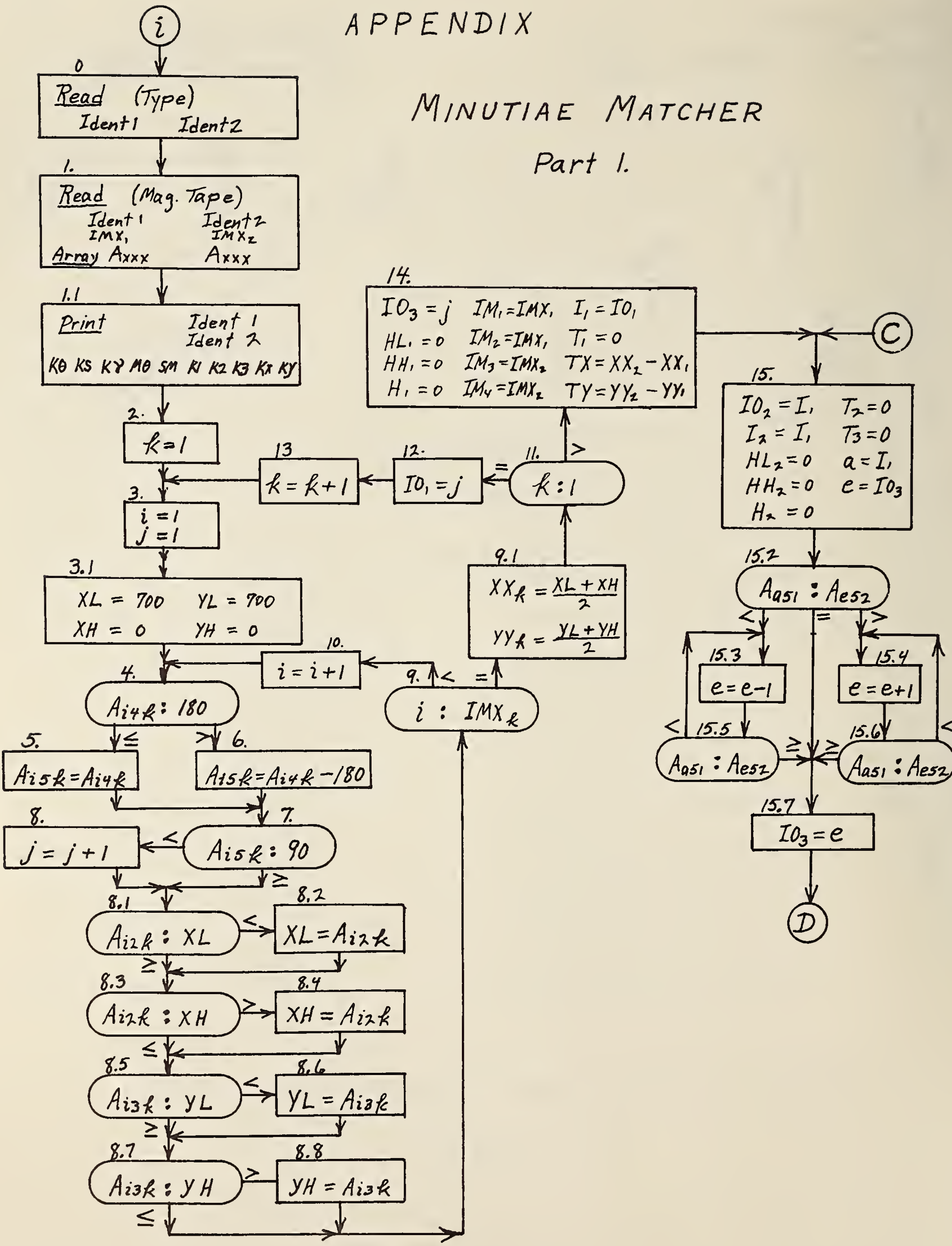
Constellations of Minutiae

Figure 7.

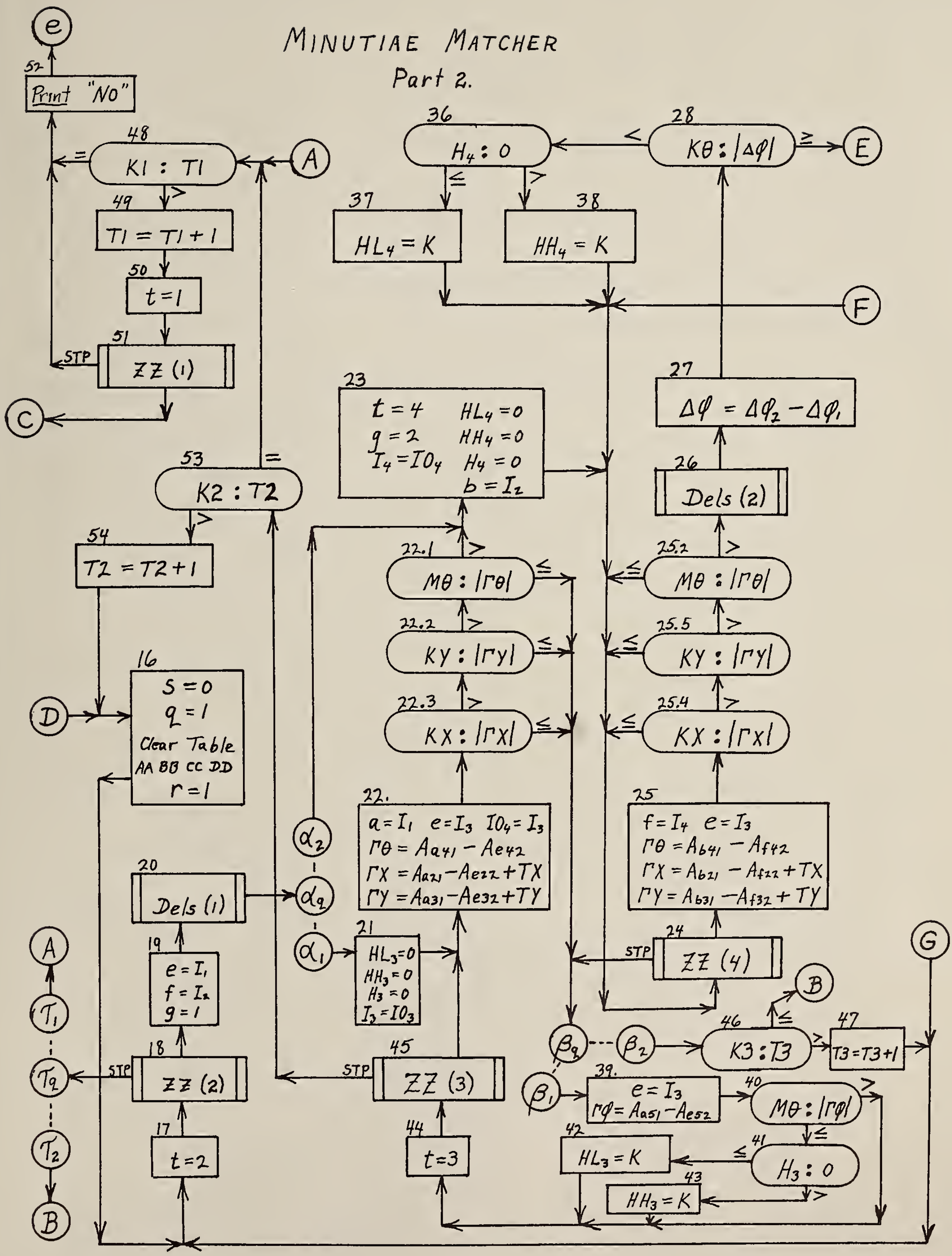
APPENDIX

MINUTIAE MATCHER

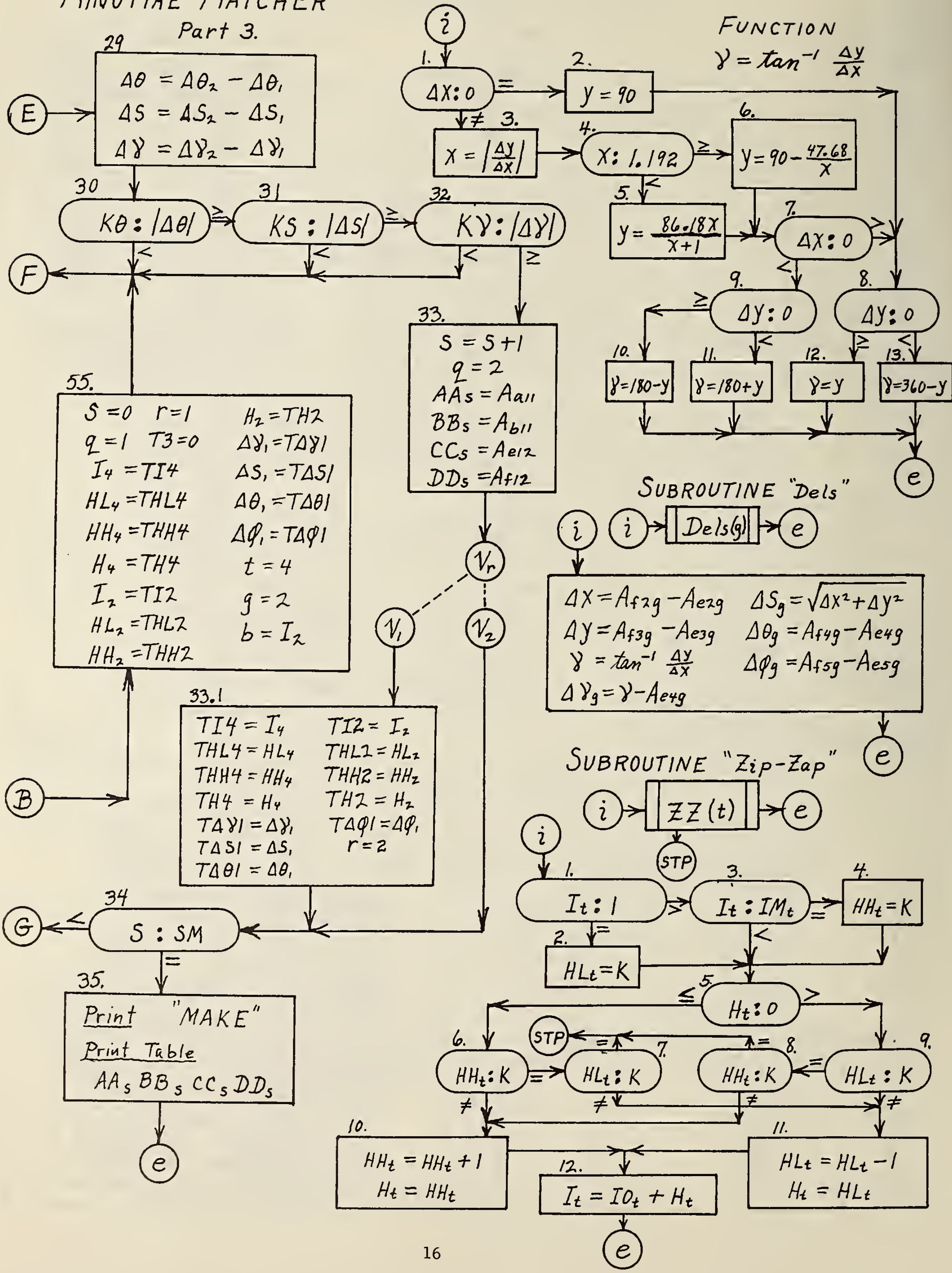
Part I.



MINUTIAE MATCHER
Part 2.



MINUTIAE MATCHER
Part 3.



NBS TECHNICAL PUBLICATIONS

PERIODICALS

JOURNAL OF RESEARCH reports National Bureau of Standards research and development in physics, mathematics, chemistry, and engineering. Comprehensive scientific papers give complete details of the work, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Illustrated with photographs, drawings, and charts.

Published in three sections, available separately:

- **Physics and Chemistry**

Papers of interest primarily to scientists working in these fields. This section covers a broad range of physical and chemical research, with major emphasis on standards of physical measurement, fundamental constants, and properties of matter. Issued six times a year. Annual subscription: Domestic, $5.00; foreign, $6.00*.

- **Mathematical Sciences**

Studies and compilations designed mainly for the mathematician and theoretical physicist. Topics in mathematical statistics, theory of experiment design, numerical analysis, theoretical physics and chemistry, logical design and programming of computers and computer systems. Short numerical tables. Issued quarterly. Annual subscription: Domestic, $2.25; foreign, $2.75*.

- **Engineering and Instrumentation**

Reporting results of interest chiefly to the engineer and the applied scientist. This section includes many of the new developments in instrumentation resulting from the Bureau's work in physical measurement, data processing, and development of test methods. It will also cover some of the work in acoustics, applied mechanics, building research, and cryogenic engineering. Issued quarterly. Annual subscription: Domestic, $2.75; foreign, $3.50*.

TECHNICAL NEWS BULLETIN

The best single source of information concerning the Bureau's research, developmental, cooperative and publication activities, this monthly publication is designed for the industry-oriented individual whose daily work involves intimate contact with science and technology—*for engineers, chemists, physicists, research managers, product-development managers, and company executives.* Annual subscription: Domestic, $1.50; foreign, $2.25*.

*Difference in price is due to extra cost of foreign mailing.

NONPERIODICALS

Applied Mathematics Series. Mathematical tables, manuals, and studies.

Building Science Series. Research results, test methods, and performance criteria of building materials, components, systems, and structures.

Handbooks. Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications. Proceedings of NBS conferences, bibliographies, annual reports, wall charts, pamphlets, etc.

Monographs. Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

National Standard Reference Data Series. NSRDS provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated.

Product Standards. Provide requirements for sizes, types, quality and methods for testing various industrial products. These standards are developed cooperatively with interested Government and industry groups and provide the basis for common understanding of product characteristics for both buyers and sellers. Their use is voluntary.

Technical Notes. This series consists of communications and reports (covering both other agency and NBS-sponsored work) of limited or transitory interest.

CLEARINGHOUSE

The Clearinghouse for Federal Scientific and Technical Information, operated by NBS, supplies unclassified information related to Government-generated science and technology in defense, space, atomic energy, and other national programs. For further information on Clearinghouse services, write:

Clearinghouse
U.S. Department of Commerce
Springfield, Virginia 22151

Order NBS publications from:

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20230

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U.S. DEPARTMENT OF COMMERCE